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EVALUATION OF INCLINATION ANGLE OF BUILDING USING MACHINE LEARNING

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ABSTRACT

For safety, buildings' structural conditions should be monitored regularly. If we can find abnormal signs, damage can be minimized. To know the normal condition of a building affected by weather, an inclination angle measurement system using a bubble tube and a focused camera has been developed. Furthermore, this system has been properly placed for monitoring a civic building. The inclination angle of a medium-rise building was measured. It is discovered that the daily cycle of the inclination angle depends naturally on solar radiation. Cyclical change of the inclination angle is conspicuous on a sunny day. The direct correlation between the change of the structure's angle and the local weather was examined using a classification method of machine learning. The daily angle change was used as input data, while the local weather of the day (sunny, cloudy, and rain) was used as output classification data. The accuracy of classification using machine learning has reached 90%. This result shows that the change of the inclination angle has been strongly affected by solar radiation. It is expected that these behaviors of buildings affected by weather can be used for the health monitoring of buildings.

KEYWORDS: Maintenance of Buildings, Sensor Network, Inclination Angle of the Building, Early Warning & Machine Learning

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Original Article

INTRODUCTION

To prevent collapse or damage of building in advance, it is important to detect a sign of abnormality. For this purpose, the daily behavior of a building should be observed. Conditions of buildings are affected by weather or earthquake. If the condition of a building deviates from the normal state, we can prepare for damage prevention in advance.

There are many studies on structural health monitoring of a building. Strain sensors are used to detect the failure of buildings[1-3)] and acceleration sensors are used to detect the vibration caused by the earthquake[4-6)].

In this paper, we present a technique to know the daily behavior of building in a simple and low-cost way. For landslide prevention, we developed a method for measuring the inclination angle using a photograph of an extremely sensitive bubble tube has been developed[7, 8)]. We improved the system for inclination angle measurement of buildings.

Tilt meters are used for geophysical research[9-14)]. These tiltmeters are precise but expensive. In this paper, a low-cost inclination angle measurement system using bubble tubes for the building has been developed, and long-

term monitoring (continuous measurement of the inclination angle) of the building has been done too. The correlation between daily change of inclination angle and weather was evaluated by a machine learning classification algorithm. This paper finds that the daily cycle of inclination angle is conspicuous on a sunny day. It is explained by the thermal expansion of the building. The daily change of inclination angle can be used as an indicator for health monitoring of the building.

INCLINATION ANGLE MEASUREMENT USING BUBBLE TUBE

Figure 1 shows the concept of a measurement system using a bubble tube (bubble tiltmeter). A camera captures the image of a bubble tube at periodic intervals. From the center position of the bubble in the image, the inclination angle is calculated. The sensitivity of the system depends on the radius of curvature of the bubble tube. The bubble expands depending on the temperature. However, the center position of the bubble comes topping the bubble tube. Therefore, this method has barely been affected by temperature, and it is unaffected by electrical noise which can be a disturbance in other measurements.

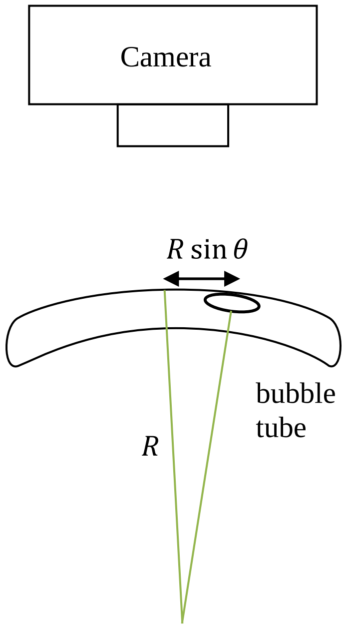
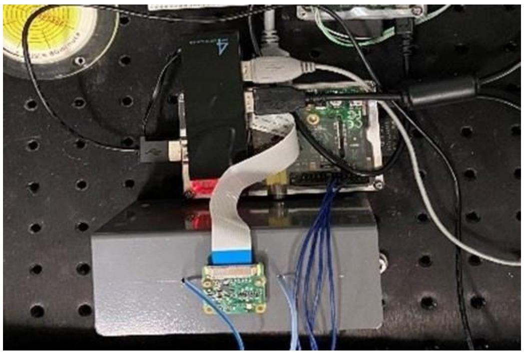


Figure 1: The Concept of a Measurement System.

Disk-shaped bubble tubes are widely used for the judgment of horizontalization. In contrast, a cylindrical bubble tube is used for precise measurement of the horizontal angle measurement. Although disk-shaped bubble tubes describe all directions, cylindrical bubble tubes include one direction. The bubble of the cylindrical tube moves along the x-direction. The cylindrical bubble tube is made by curving the cylindrical glass tube and it has alcohol.

Measurement error for this method was evaluated[7)]. This method is affected by the curvature of the bubble tube, the viscosity of the liquid in the bubble tube, size of the bubble, resolution of the camera, and temperature. It is difficult to define the precise accuracy of this system, however, angular change of fewer than 0.002 degrees can be measured. And developed systems had compared each other. This value is sufficient for the measurement of the building.

A cylindrical bubble tube with a radius of curvature of 20,000 mm was used. The length and the diameter of the bubble tube were 120 mm and 13mm, and the length of the bubble was 50mm.



(a) Developed System (All System top view)

(b) Bubble Tube Tiltmeter

Figure 2: Real Photos of the Developed System and Bubble Tube Tiltmeter.

Raspberry Pi and Pi-camera (which is a small camera module easily controlled by Raspberry Pi) were used for measurement. Figure 2 presents (**a**) the developed system, and (**b**) an example of a photo image that used to be as input for the system to read the angle. The resolution of the image is 1280*1024 pixels. The developed program is designed by Python. The cost of the system is approximately $150: specially ordered bubble tube is $100 and Raspberry Pi and camera are $50. A network connection environment is necessary additionally.

The images were captured every 30 minutes, and their processing method was used for automatic measurement. Only the x-axis position of the center of the bubble is necessary. However, the length of the bubble changes. Therefore, the positions of the right edge and the left edges of the bubble as shown in Figure 2 were measured.

Then two template images: the left edge and the right edge of the bubble were prepared. Template matchings for each edge were applied separately and the x-axis position of each edge, x_1, and x_2 is determined. The template matching was done with OpenCV. The average value of the x-axis positions of the right edge and the left edge corresponds to the center position of the bubble.

The angle is calculated by the following equation:

$$\theta = \frac{x_1 + x_1}{2}\frac{1}{R} \qquad (1)$$

θ is the angle of the system (radian) and R is the radius of curvature of the bubble tube. The developed system was calibrated by a goniometer and an acceleration sensor (ADXL355).

CONTINUOUS MEASUREMENT OF BUILDING

The inclination angle of the building for a long period was monitored. The developed system was set near the center of the seventh floor of an eight-story building of the Ibaraki University Hitachi campus. The system was fixed on the concrete bed. There are no worries about getting wet in the rain.

Figure 3: Hitachi Campus Map / Experimented Building is E5-8th Storey[15)].

Figure 3 shows the campus map, E5 building which was experimented on. The bubble tube was set along the East-West direction.

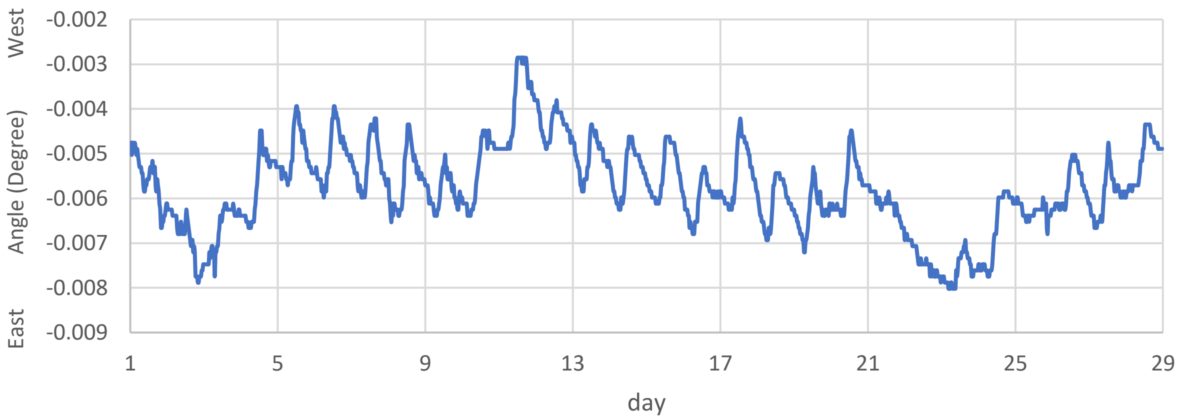


Figure 4: The Angular Change for February 2018.

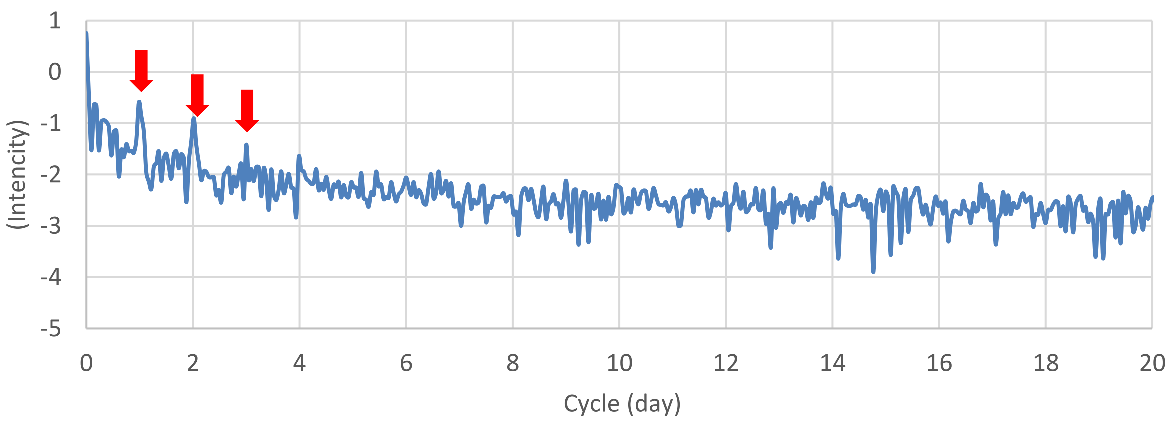


Figure 5: The Power Spectrum of the Angular Change for February 2018.

Figure 4 shows the angular change in an east-west direction for a month. The daily cycle can be found. The amplitude of the daily change of angle is approximately 0.001 degree. **Figure 5** shows the power spectrum of **Figure 4** There is a peak where the cycle is one day. There are lesser peaks at the second harmonics of a one-day cycle, and it is presented by the red arrow in **Figure 5**.

The leaning of the building is caused by partial solar radiation. **Figure 6** shows the concept of leaning of the building caused by solar radiation. The eastern side and the western side expand in the morning and the afternoon, respectively.

Figure 7 shows the difference of solar radiation in sunny days and cloudy and rainy days. The sunshine is scattered by clouds as shown in **Figure 7** (**b**). Therefore, the daily change of the inclination angle is unnoticeable on cloudy and rainy days. Generally, clouds are thick on rainy days, so the effect of solar radiation is weakened.

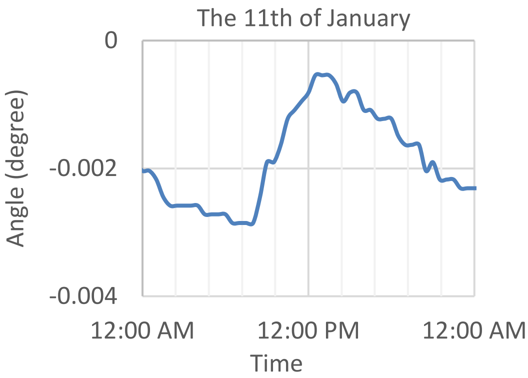
Figure 8 presents an example of the angular change of sunny, cloudy, and rainy days. The cyclic change is clear on a sunny day. The amplitude of the daily change of the angle obtains 0.002 degrees.

(a) Morning Time **(b) Afternoon Time**

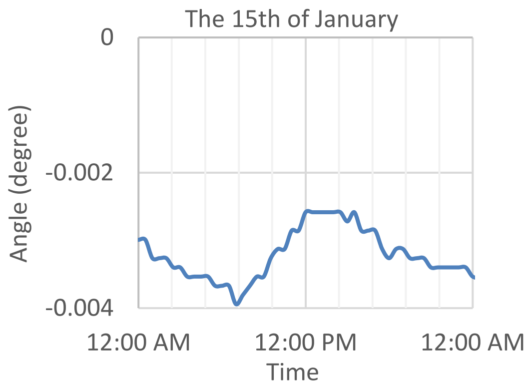
Figure 6: The Concept of Leaning of the Building Caused Solar Radiation.

(a) Sunny Days **(b) Cloudy and Rainy Days.**

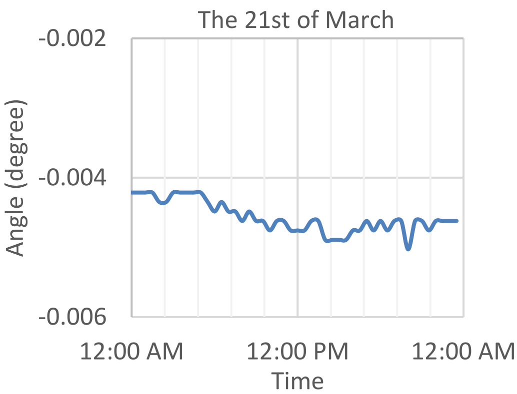
Figure 7: Difference of Solar Radiation caused by Clouds.



(a) Sunny Day



(b) Cloudy Day



(c) Rainy Day

Figure 8: Example of the Angular Change in 2018.

CLASSIFICATION DATA BY MACHINE LEARNING

If the daily change of angle of the building has a good relationship with the weather, this value may be used as one of the indicators for health monitoring of buildings. Unexplained angle data may imply the damage of buildings. Therefore, we used machine learning to evaluate the relationship between the weather and inclination angle.

Recently, machine learning has been used in various fields related to AI (Artificial Intelligence), and it was useful in classification. For our case, the classification algorithm, sets of input objects, and output values are prepared. Each input object corresponds to an output value. The output value corresponds to the group of classification. The machine learning program learns the relation between input objects and output values using data sets for training. After the learning completes, the program can identify the category of an input object. Some machine-learning libraries, Scikit-learn, Keras, and TensorFlow, are available for Python programming[16)].

The relation between the daily angular change of the building, the weather, and the solar radiation was evaluated by using a machine learning program. 341 data for 2018 were prepared. The data was divided into 272 data-input for learning and 69 for testing the learning. The input object has 48 angle data, every 30 minutes of a day. The angle data were transformed to relative value, by subtracting the first angle data of the day from each angle data. The first angle data of each day was set to 0 degrees.

Table 1: Categories and Encoding Table.

Day Weather	Encoding
Sunny day	[1,0]
Cloudy day and rainy day	[0,1]

(a) Two Categories Encoding

Day Weather	Encoding
Sunny day	[1,0,0]
Cloudy day	[0,1,0]
Rainy day	[0,0,1]

(b) Three Categories Encoding

The output categories are based on the weather of the day as sunny, cloudy, and rainy. The output value is given as a form of a vector, which is known as one-hot encoding as presented in **Table 1** Categories and encoding table. (**a**) Two categories encoding; (**b**) Three categories encoding.

Two cases of classifications: Classification to three, (sunny), (cloudy), and (rainy) and classification to two categories (sunny), and (cloudy or rainy) was evaluated.

Scikit-learn and Keras for machine learning were used. In Scikit-learn, the algorithm of Support Vector Machines (SVM) was used. SVM is widely used for linear and non-linear classifications. Two hidden layers of 200 nodes were used for Scikit-learn and Keras.

Table 2: The Accuracy of Classification

Categories Method	2 Sunny and (Cloudy or Rainy)	3 Sunny, Cloudy, and Rainy
Scikit-learn	92% (33/36)	86% (31/36)
Keras	94% (34/36)	83% (30/36)

Table 2 displays the result of learning. When there are two categories, the accuracy of classification is 90%. This result means the daily change of the building along the east-west direction is affected by solar radiation. When there are three categories, the accuracy of classification is 80%.

The effects of a cloudy day and a rainy day on the inclination angle daily change were close to each other; thus, it is difficult to distinguish between cloudy and rainy. The difference between the accuracies of the classification by the Scikit-learn or Keras is small.

We can consider the daily change of inclination angle as an indicator of the condition of the building which is strongly affected by the weather. If we can find unexplainable behavior, it may be a signal of failure of the building. However, this research work is only one example. Daily changes are variously different depending on the structure of the building. Further experiments on various buildings are necessary for practical applications.

CONCLUSIONS

An inclination angle measurement system for the building was developed. Photo images of bubble tubes were turned into angle data by template matching. 341 days (about 11 months) of data in 2018 (Each one-day data includes the angle of the building each 30 min, 48 angles a day.) was studied. It was detected that the building leans to the west in the morning and the east in the afternoon. This effect is noted on a sunny day.

Obtained data were evaluated by the machine learning algorithm using python. The change of angle and the weather of each day were analyzed by a classification algorithm. When it was classified into 2 groups, the accuracy of

classification reached 90%. This indicates that the movement of buildings is affected by the weather. The daily change of inclination angle is expected to be used as an indicator for the health monitoring of buildings. It is expected that faults in the building structure will be found from the unexplainable change of inclination angle.

DECLARATION OF CONFLICTING INTERESTS

The author(s) declared no potential conflicts of interest concerning the research, authorship, and/or publication of this article.

AUTHOR CONTRIBUTIONS

Investigation, Data curation, Methodology, Formal analysis, and Writing – original draft, MOHAMAD NAJIB ALHEBRAWI; Supervision, Conceptualization, Resources, Data curation, Project administration, Writing – review and editing, ATSUSHI MINATO.

AVAILABILITY OF DATA STATEMENT

The raw/processed data required to reproduce these findings cannot be shared at this time as the data also forms part of ongoing research.

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REFERENCES

1. *J. Bures, L. Klusacek, R. Necas, and J. Fixel, "Verification of strain gauge and geodetic measurements during long-term monitoring of Gagarin bridge in working conditions," 2016, pp. 33-37.*
2. *H. Li and W. Zhou, "Stochastic subspace-based structural identification and damage detection ‚Äì Application to a long span cable-stayed bridge," 2008.*
3. *J. Zhang, S. Guo, Z. Wu, and Q. Zhang, "Structural identification and damage detection through long-gauge strain measurements," Engineering Structures, vol. 99, no. 99, pp. 173-183, 2015.*
4. *D. Yang, Earthquake warning system based on acceleration sensors and earthquake parameter acquisition method, 2018.*
5. *M. Pozzi, D. Zonta, D. Trapani, N. Athanasopoulos, A. J. Amditis, M. Bimpas, A. Garetsos, Y. E. Stratakos and D. Ulieru, "MEMS-based sensors for post-earthquake damage assessment," Journal of Physics: Conference Series, vol. 305, no. 1, p. 12100, 2011.*
6. *M. Dumont and D. Wolf, "Usage of MEMS Capacitive Acceleration Sensors for Structural Monitoring", pp. 77-89, 2019.*
7. *G. F. A. Nisha, "Development of Wireless Sensor Network System for Inclination," Dr thesis, Ibaraki University, 2016.*
8. *G. A. Nisha, N. Warnajith, H. Tsuchida and A. Minato, "Wireless sensor network system for inclination measurement using spirit level,", Int. J. Modern Engineering Research, vol. 5, no. 4, pp. 1-8, 2015.*
9. *G. Mentes, "Atmospheric tide obtained by the microbarograph developed at the Geodetic and Geophysical Research Institute of the Hungarian Academy of Sciences," Acta Geodaetica Et Geophysica Hungarica, vol. 39, no. 1, pp. 39-48, 2004.*

10. G. Buchbinder, A. Lambert, R. Kurtz, D. Bower, F. Anglin, and J. Peters, "Twelve years of geophysical research in the Charlevoix seismic zone," Tectonophysics, vol. 156, no. 3, pp. 193-224, 1988.
11. S. Constable, "Review paper: Instrumentation for marine magnetotelluric and controlled source electromagnetic sounding," Geo-physical Prospecting, vol. 61, pp. 505-532, 2013.
12. J. A. Westphal, M. A. Carr, W. F. Miller, and D. Dzurisin, "Expendable bubble tiltmeter for geophysical monitoring," Review of Scientific Instruments, vol. 54, no. 4, pp. 415-418, 1983.
13. M. Tolstoy, S. Constable, J. Orcutt, H. Staudigel, F. K. Wyatt and G. Anderson, "Short and long baseline tiltmeter measurements on axial seamount, Juan de Fuca Ridge," Physics of the Earth and Planetary Interiors, vol. 108, no. 2, pp. 129-141, 1998.
14. H. Sato, H. Takahashi, E. Yamamoto, N. Fukuo, M. Uehara and Y. Terasawa, "Development of the Crustal Tilt Observation Method Using Borehole-type Tiltmeters," Journal of the Seismological Society of Japan, vol. 33, no. 3, pp. 343-368, 1980.
15. " Ibaraki University Admission Guide 2013," [Online]. Available: http://www.ibaraki.ac.jp/common/pdf/guidance/guide2013.pdf. [Accessed 25 7 2021].
16. C. Müller and S. Guido, Introduction to Machine Learning with Python: A Guide for Data Scientists, 2016.

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Mohamad Najib Alhebrawi received his Bachelor of Engineering from Mutah University in Kerak, Jordan in 2017, researching in deferent fields like Structural Engineering Analysis, Foundation Engineering, and Construction Methods. Then he received his Master of Engineering in the field of Construction and Environmental Engineering, Specialized in Architectural Structure Engineering from Ashikaga University in Tochigi, Japan in 2020, researching and analyzing, structural vibration, to demonstrate their properties and stability. And researching the use of robots in civil engineering to increase accuracy, productivity and enhance safety. Now he is a doctoral student at the Department of Social Infrastructure System Science, Graduate School of Science and Engineering, Ibaraki University in Ibaraki, Japan. His research interests are Structural Health Monitoring and the application of Machine Learning.

Atsushi Minato received his Bachelor of Science from Kyoto University in 1984. After working as an engineer at a company, then he received his Master of Engineering and his Doctor of Engineering from the University of Tokyo between 1988 and 1994. He was a researcher at the National Institute of Environmental Studies from 1988 to 1995. He moved to Ibaraki University in 1995 as a lecturer. His research interests are the development of IoT systems, Manufacturing Technology, Measurement Engineering, Nanotechnology/Materials, Image Analysis, Informatics, and the application of Machine Learning. He is a member of (the Institute of Electronics, Information and Communication Engineers), (the Society of Instrument and Control Engineers), and (the Society of Life Support Engineering). Currently, he is a professor at the Graduate School of Science and Engineering at Ibaraki University.